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# Decision Support for National Sustainable Energy Strategies in an Integrated Sustainability Assessment Framework

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## 1. Introduction

### 1.1 A new context for knowledge production

Though apparently very straightforward, each concept figuring in the title of this chapter is actually quite problematic considering the nature of contemporary energy system governance. First, the concept of ‘decision support’ seems to suggest that ‘supporting’ a decision can be delineated sharply from actually ‘taking’ a decision – with the first task being safely entrusted to ‘scientists’ who provide the ‘facts’ (i.e. the solid grounds) on which a decision is to be based; the second task belonging to ‘decision makers’ with authority, power and legitimacy to take decisions in pursuing ‘societal values’. This mechanistic separation is to be rejected because value-based arguments and decisions inevitably enter the phase of constructing ‘facts’ (Latour, 2004), also in energy policy decision making (Kraus, 1987). Second, the aspect ‘national’ energy strategy is challenged by an increasingly globalised energy economy, *a fortiori* in many Western countries where energy markets are liberalising and responsibilities for energy system governance are moving up to international institutions, down to regional organisations, and/or out to non-state actors (Rhodes, 1996). Further, economic and governance activities impinging on energy system development are unstructured and complex and cannot be an object of calculation, management, or governance by any form of ‘centralised’ authority. Instead such practices are oriented to subsets of energy-economic relations that have been discursively and often organisationally and institutionally fixed as objects of intervention (Miller & Rose, 1990). Third, ‘integrated sustainability assessment’ suggests a resemblance to ‘environmental impact assessment’. Although the latter is a streamlined procedure imposed in many jurisdictions on the development of energy infrastructures (Petts, 1999), the former still remains ambiguous and contested. A coherent body of knowledge and/or practical guidance are still missing (Jordan, 2008).

No component of ‘decision support for national sustainable energy strategies in an integrated sustainability assessment framework’ is readily available. This challenges policy makers and analysts alike, because our energy systems must evolve to a more

sustainable direction. This necessitates reliable assessment tools for monitoring progress and commanding the 'best available science'. Even with the nation state's steering capacities in energy policy diminishing since the 1960/70s, national states remain critical actors in international negotiations on climate and energy policy (Lesage et al., 2010), and key sites of political accountability and public legitimacy (Gamble, 2000). 'Decision support for national sustainable energy strategies in an integrated sustainability assessment framework' is an important issue, but the key components require rephrasing as follows:

- 'Scientific decision support' is necessary for providing **explanatory knowledge** about energy systems – i.e. knowledge about socio-economic activities, future demand for energy services, energy supply and demand technologies and the resulting impacts. But such knowledge cannot be considered as 'objectively given'; it should be 'negotiated' in the course of the sustainability assessment process. In addition to traditional objective selectors for explanatory knowledge like controllability, reproducibility and non-ambiguity, subjective and inter-subjective selection criteria have to be made explicit (for playing a role). The latter criteria refer to the suitability of knowledge to be internalised by individuals (criteria like utility, simplicity, etc.). They also refer to the degree of acceptance of an idea within a group (criteria like collective utility, expressiveness, authority of the knowledge source, etc.);
- In the likely absence of a generally accepted blueprint for a sustainable energy system, formulation of national sustainable energy strategies must emerge from interactive and inclusive processes of social dialogue and reflection. The processes are guided by **orientation knowledge** of justification arguments used by different (sets of) stakeholders;
- Integrated sustainability assessment is not only a scientific methodology, but also a 'value-articulating institution' (Stagl, 2009). Because (sustainability) valuation methods determine *inter alia* who participates in the valuation process, how they participate and in what capacity (e.g. as citizen, consumer, expert, stakeholder), what counts as trustworthy data, and which data processing and aggregation procedures are used, the outcomes of such methods go beyond a rational selection of the 'best possible option' in two senses. First, outcomes are influenced by how participants are invited to contribute to the valuation, information is provided and questions are stated. Different stakeholders may exhibit different 'rational choices' in a given situation, and there are no neutral grounds to identify the 'best option'. Second, the outcomes of valuation processes can actually influence the behaviour of those participating in the valuation. In this sense, valuation processes (such as integrated sustainability assessment) can be regarded as institutions. Therefore, sustainability assessment methods also need to be **reflexive** and sensitive to the processes of knowledge production. Society and policy makers not only need action-guiding knowledge, but also need to develop an awareness of how to interpret knowledge including the inevitable uncertainties. Reflexivity should extend to the functioning of 'traditional' decision support tools (such as energy system models, multi-criteria decision aiding techniques, or cost-benefit analysis) in an institutionally-anchored sustainability assessment framework. Reflexive governance will also create a better understanding of the nation state's role in devising sustainable energy strategies.

## 1.2 The SEPIA project

This chapter presents reflections on an innovative national energy policy decision support architecture based on experiences gained from the SEPIA project<sup>1</sup>. SEPIA investigates decision support methodologies, procedures, structures and tools for a sustainable energy policy with a focus on stakeholder involvement. It combines participatory fuzzy-set multi-criteria analysis with narrative scenario building and (quantitative) energy system modelling using the LEAP model<sup>2</sup>. The goal of SEPIA is to develop and discuss the feasibility of the main components of sustainability assessment in the Belgian energy policy context. Identifying elements of consensus and of dissent across stakeholder groups about possible designs of sustainability assessment provides a basis for an sustainability assessment procedure adapted to the Belgian energy governance, particularly embedded in a multi-level governance structure. SEPIA explicitly acknowledges socio-political and normative backgrounds of participants in the debate on energy issues and choices, including sustainable energy.

The project encompasses 4 phases, running over three years (Jan. 2008 – Dec. 2010): i) methodological reflections on sustainability assessment (Jan. 2008 – June 2008); ii) participatory construction of long-term sustainable energy futures and a value tree including sustainability criteria (July 2008 – June 2009); iii) deliberation on these futures with the aid of a fuzzy-set multi-criteria decision support tool (July 2009 – June 2010); and iv) reporting and dissemination of results (July 2010 – Dec. 2010). Sustainability assessment of long-term energy scenarios using qualitative and quantitative data and multi-criteria decision tools requires both a ‘holistic’ and a ‘partial’ assessment (i.e. an assessment of both the ‘whole picture’ presented by a scenario storyline as well as the different dimensions of sustainability). Also stakeholders must accept the assessment as methodologically sound and legitimate. Since SEPIA is still ongoing at the time of writing this contribution, we cannot present definite results. This chapter discusses from a conceptual and methodological perspective the challenges in providing explanatory, orientation and reflexive knowledge in a new context of knowledge production. We proceed from an overview of the ‘state-of-the-art’ of sustainability assessments (Section 2.1), (energy) foresight (Section 2.2) and multi-criteria analysis (Section 2.3). Next, we show how SEPIA combines the three domains by a detailed account of the methodological choices made in the course of the project (Section 3). The chapter ends with conclusions and observations and offers reflections on future research needs (Section 4).

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<sup>1</sup>SEPIA stands for ‘Sustainable Energy Policy – Integrated Assessment’. The SEPIA project is carried out by 5 partners: the University of Antwerp (UA, acting as the co-ordinator), the Free University of Brussels (VUB), the University of Liège (ULg), the Flemish Institute for Technological Research (VITO) and the Belgian nuclear research centre (SCK•CEN). It is funded by the Belgian office of science policy. Further details can be found at the project website <[www.ua.ac.be/sepia](http://www.ua.ac.be/sepia)>.

<sup>2</sup>LEAP stands for ‘Long range Energy Alternatives Planning system’. LEAP is an integrated modelling tool that is used to track energy consumption, production and resource extraction in all sectors of an energy economy. More information on LEAP is available at <[www.sei-international.org/leap-the-long-range-energy-alternatives-planning-system](http://www.sei-international.org/leap-the-long-range-energy-alternatives-planning-system)>.

## 2. Methods for strategic decision making on sustainable energy development

### 2.1 Integrated sustainability assessment

#### 2.1.1 Planning, networking and 'futuring'

Integrated assessment in the context of sustainability is necessarily predicated (to a greater or lesser extent) on 'foresight' abilities, i.e. of thinking, shaping or debating the future. This is quite clear on an intuitive level: despite the obvious uncertainties inherent in any attempt at 'foreseeing' the future, some form of future anticipation is simply implied in human decision making of all sorts, as is evident in associated notions of intentionality, accountability, responsibility, etc. which are all necessarily predicated on assumptions of a (certain degree of) anticipation. More specifically, according to Meadowcroft (1997: 429-431) foresight in integrated sustainability assessment relates to a mix of planning, networking, and futuring activities:

- **Planning** is needed because it is generally assumed that sustainable development (in any field) is unlikely to be achieved by spontaneous social processes, or as the 'unintended consequences' of seeking other ends (e.g. maximising profits in markets). Therefore, sustainable development requires the explicit attention and intervention of some 'governing agency'. The foresight component of planning relates to exploring possible futures or developing visions for the future, identifying possible impacts of certain policy measures, testing the robustness of policy measures under different imaginable futures, etc.;
- **Networking** is needed because governments alone cannot bring about the sweeping changes needed for a (more) sustainable development, but depend on a host of other actors (e.g. business, labour unions, NGOs, the media, etc.) (cf. Section 1.1). The foresight component of networking relates to deepening dialogue on problem framings, mapping different problem definitions and checking for societal support, looking for future possibilities to surpass or reconcile conflicting views, etc.;
- **Futuring** (defined as the ensemble of methodologies or support tools to help reflecting on the future) is needed because the realisation of sustainable development requires 'methodological attitudes' to deal with an uncertain future, since governments must act in a consistent way over time to realise policy objectives.

Integrated sustainability assessment involves different types of knowledge flows within each activity and across activities, therefore different types of information, audiences and processes are expected, as illustrated in the next section (Section 2.2).

#### 2.1.2 'Policy as calculus' and 'Policy as discourse'

The different approaches to integrated sustainability assessment can be illustrated further by situating them within the wider governance framework in which these assessment processes play a role. Paredis et al. (2006) make a useful distinction between two ideal-typical governance 'styles' – called respectively "**Policy as calculus**" and "**Policy as discourse**". These 'styles' illustrate the two extremes of a spectrum of choices available to policy makers interested in setting up governance mechanisms for sustainability. They see sustainable development as a wider process of change engaging with an entire network of (policy, commercial, civil society, etc.) actors, institutions, technical artefacts, etc. However, both perspectives differ in the way they approach the generation of strategic (i.e. explanatory, orientation and reflexive) knowledge needed for steering this change process in the direction of a sustainable future. Put very briefly, 'Policy as calculus' represents a



‘closed’ process heavily predicated on expert input and agreement, whereas ‘Policy as discourse’ ‘opens up’ to a wider range of actors, disciplines and concerns. Both perspectives are compared on a number of attributes in Table 1. A SWOT analysis is made in Table 2.

**“Policy as calculus”** assumes that knowledge-based decision support – and the decision processes built on this support – can be conceptualised separately from its ‘socio-technical object’ (e.g. the energy system). For recommending how to steer socio-technical change in more sustainable directions, expert analysts should ‘step outside’ the system to objectify its workings. Governance is characterised in terms of exogenous ‘mechanistic’ interventions. In all of this, an important role is attributed to ‘expert input’. This does not exclude stakeholder involvement for providing ‘inputs’ to the assessment process. But separate stakeholders are assumed of holding a ‘jigsaw puzzle’ piece that experts collect and layout to compose a picture of the ‘socio-technical object’. As such stakeholders are no more than ‘carriers’ of policy alternatives, information, and value judgements. It is assumed that all stakeholders observe ‘the same’ object, but they each tend to prioritise or focus on a limited set of aspects related to this object. Once the relevant pieces of the puzzle are collected (i.e. e.g. objectives are clearly defined and agreed upon, all necessary data are available, cause-effect relations are established, etc.), the ‘solution’ to the governance problem follows ‘logically’ from aggregating the different perspectives by using for example economic optimisation models, multi-attribute utility theory, etc. The appraisal process ‘closes down’ on the single socio-technical object – i.e. it is about “...*finding the right questions, recruiting the appropriate actors (actors with ‘relevant’ insights), highlighting the most likely outcomes and therefore also defining the best options...*” (Smith & Stirling, 2007: 6). Once the appraisal procedure has aggregated all relevant information, the instruments for intervening in the dynamics of socio-technical objects follow mechanically (e.g. when economic evaluation finds nuclear power as ‘best option’ policy instruments must clear the ‘barriers’ of a full nuclear deployment). Politically this approach implies that ‘relevant actors’ bring their commitments in line with the recommendations from the appraisal. The alignment job is left to the political decision makers, in devising appropriate tools to persuade, entice or simply force actors to realize the path set out by ‘the experts’.

	Policy as calculus	Policy as discourse
Role of sustainability assessment	Sustainability assessment as a tool for selecting the best alternatives in order to reduce negative sustainability impacts	Sustainability assessment as a framing process of deliberation on ends and means
What matters for political planning?	Uniform solutions based on technical and economic expertise	‘Framings’, deliberation, perspective-based testing of hypotheses involving a wide range of disciplines (including but not limited to economics and engineering)
Leading actors (networking)?	Context-dependent, with a focus on academics (with demonstrable expertise in the relevant scientific disciplines) and government actors	Context-dependent, with a focus on experts (e.g. academics, professionals with experience in relevant fields, etc.), stakeholders (representative of the different ‘problem framings’), and government actors

Foresight methods?	Mostly quantitative (i.e. modelling), explorative trend analysis (based on ‘what if’ reasoning)  Government actors and/or stakeholders as ‘clients’	Mostly qualitative (i.e. sociological) analysis (based on ‘what is desirable’ reasoning) with quantitative analysis as a support  Government actors and/or stakeholders providing crucial inputs
Methods and tools (futuring, planning, networking)	‘Standard’ scientific methods, e.g. mathematical models, cost-benefit analysis, cost-effectiveness analysis, checklists, matrices	Deliberative methods (e.g. scenario workshops, expert panels, focus groups, etc.) with ‘standard’ scientific methods as supportive
What is maximised?	Planning – i.e. simple answers to complex problems, clear-cut recommendations about specific proposals	Networking – i.e. interdisciplinary scientific knowledge, participation, deliberation, individual and societal learning effects
Procedurally effective if...	The optimal alternative has been identified  Trade-offs are based on scientifically tested methodologies  The proposal is of better quality (in the sense that negative impacts are avoided or mitigated) after the realisation of the assessment	Ideally, the deliberative process produces consensus by actually changing minds through reasoned argument  A political community has been created around an issue  Decision-making culture and practice have changed  Sustainability assessment is iterative and fully integrated within the policy process, giving adequate and timely inputs to policy formation  Transformative effect – acceptance of new goals and guiding principles for the energy transition
Procedurally efficient if...	A solution is found with minimum expenditure of available resources (time, money) and expertise (state-of-the-art knowledge) for the sustainability assessment	The sustainability assessment is carried out according to a clear and achievable timetable, giving enough time and resources for preparation of the process and stakeholder engagement
Procedurally fair if...	The recommended alternative(s) are justified by established expert authority, e.g. accredited research institutes, peer review, lauded academics, etc.	No legitimate point of view is excluded a priori from the assessment  Power differentials between social actors are neutralised

Table 1. Two different views on governance for sustainability (based on Paredis et al., 2006; Smith & Stirling, 2007)

	Policy as calculus	Policy as discourse
Strengths	Practical instrument resulting in univocal recommendations from a ‘narrow’ framing perspective  Part of the existing decision-making process in many countries	Sustainability raised as a collective concern  Improved decision-making process
Opportunities	Political demand for this kind of exercises  Use of existing knowledge and know-how  Practical experience with similar exercises (Environmental Impact Assessment, Regulatory Impact Assessment)	Can build on existing participatory arrangements  Scientific and political momentum in favour of sustainable development; acceleration of global change signals calls for ambitious action
Weaknesses	Attempt to include all aspects of sustainability in quantitative models faced with difficulties: unavailable data, uncertainties, etc.  Environmental, governance and equity concerns are marginalised  Acceptance of unlimited substitutability implies ‘weak sustainability’	Representativeness of involved and missing stakeholders  Potential to yield practical recommendations in due time  Difficult to institutionalise  Additional (and multidisciplinary) expertise, data, tools and time required compared to ‘policy as calculus’
Threats	Technocracy and bureaucracy  Reductionist perspectives are encouraged  Risk of imbalance towards incremental approaches and consequent marginalisation of long-term sustainable development objectives	Lack of practical experience in conducting sustainability assessment exercises, leading to unrealistic expectations  Manipulative interventions by some participants, eventually ending in demagoguery  Resistance against potentially transformative power of the sustainability assessment

Table 2. SWOT of ‘Policy as calculus’ and ‘Policy as discourse’

“**Policy as calculus**” starts from the premise that there is no unique ‘objectively rational’ position from which a ‘socio-technical object’ (e.g. the energy system) can be observed. System boundaries, interrelations between system components, opinions on what causes change, etc. (in short: ‘framings’) vary according actor perspectives, and may change during various stages of the appraisal. Because different ‘framings’ imply different methodologies for arriving at ‘relevant’ knowledge about the ‘socio-technical object’, input to the sustainability assessment cannot be ‘imposed’ but has to be negotiated. The same applies for the criteria guiding the



sustainability assessment, which have to be checked for legitimacy and acceptance. Assessment does not identify the 'best possible' pathway for the evolution of the 'socio-technical object', but rather tests its evolution under the different 'framings' brought to the table by stakeholders. As a consequence, no unique set of ideal policy instruments can be identified; recommendations will always be much more 'conditional' (e.g. *'option x is the preferred option under framings a and b, but does not score well under framing c', 'option y scores rather well under all framings, and can therefore be considered as a robust option'*, etc.).

The difference between 'policy as calculus' and 'policy as discourse' should not be conceived along the lines of a stark dichotomy between "...established, narrow, rigid, quantitative, opaque, exclusive, expert-based, analytic procedures tending to privilege economic considerations and incumbent interests..." and the "...new, relatively unconstrained, qualitative, sensitive, inclusive, transparent, deliberative, democratically legitimate, participatory processes promising greater emphasis on otherwise marginal issues and interests such as the environment, health, and fairness..." (Stirling, 2008: 267). To support this point of view, Stirling points out some examples of 'bottom-up participatory initiatives' by design which in their practical implementation and outcomes are better understood as 'top-down exercises in legitimization', and conversely also of 'expert-based analytic processes' which are more conducive to enhanced social agency than their participatory counterparts. In other words, according to Stirling (2008) the detailed context and implementation of a particular governance approach are more important factors to understand what happens in practice. Instead of an illustration of the opposition between an 'expert-based' and a 'deliberative' governance approach, the difference between 'policy as calculus' and 'policy as discourse' should be seen as illustration of how assessments and/or commitments can be 'closed down' (in the case of 'policy as calculus') or 'opened up' (in the case of 'policy as discourse') in an institutional environment which is structured and pervaded by power relationships. If appraisal is about 'closing down' the formation of commitments to policy instruments or technological options, then the aim of the assessment is to assist policy makers by providing a direct means to justify their choices. If, on the other hand, the assessment is aimed at 'opening up' a process of social choice, then the emphasis lies on revealing to the wider policy discourse any inherent indeterminacies, contingencies or capacities for action. Of course, expert-based analytic approaches such as cost-benefit or cost-effectiveness assessment are frequently practiced as part of a 'policy as calculus' approach, but these techniques might equally lend themselves to an 'opening up' philosophy (Stagl, 2009).

In order to define adequately which features of both 'philosophies' SEPIA adopts, a thorough analysis of the existing energy policy context and the institutional landscape is a prerequisite. In practice, the dominant approach in Belgium to decision support in energy policy has followed more or less the 'policy as calculus' philosophy. Therefore, we consider there is both in academic discussion as in policy practice some scope for a more symmetrical interest in processes for 'opening up' the debate on long-term sustainable energy strategies. SEPIA had to find an adequate balance between moment of 'opening up' and 'closing down' assessments, and choose the appropriate methods accordingly. These methodological choices are explained further in section 3.

## 2.2 Foresight methodology

The term '*futuring*' (section 2.1.1) refers to the ensemble of scientific tools used to support foresight, for example forecasting techniques, envisioning workshops, modelling tools,

brainstorming sessions, etc. Broadly speaking, futuring activities aim at deliberate and systematic thinking, debating or shaping of the future. In practice, futuring approaches come in many different shapes and forms (van Notten et al., 2003). A first distinction is between **predicting** and **exploring** the future. Earlier attempts at forecasting (prediction) have proven to be largely unsuccessful (particularly in the case of long-term energy foresight) and are increasingly being abandoned by foresight practitioners – although expectations of correct prediction on the part of policy makers are still apparent. Next, there is the difference between **quantitative** (modelling) and **qualitative** (narrative) traditions with the former prevailing in the field of energy. Hybrid approaches combine narrative scenario development with quantitative modelling. Also are distinguished descriptive or **exploratory** futuring approaches describing possible developments starting from what is known about current conditions and trends, from normative, **anticipatory** or backcasting approaches constructing scenario pathways to a desirable future. Neither approach is ‘value free’, since both embody extra-scientific judgments, for example about ‘reasonable’ assumptions. But the objectives of the scenario development exercise determine the choice between exploratory and anticipatory approaches. Exploratory (or ‘what-if’) analysis articulates different plausible future outcomes, and explores their consequences. Prioritising technological choices, technical and economic experts perform the analysis in a relatively closed process, with government actors mostly assuming the role of client (they ‘order’ the analysis). Anticipatory scenarios represent organised attempts at evaluating the feasibility and consequences of achieving certain desired outcomes or avoiding undesirable ones. Finally, **trend** scenarios based on extrapolations of (perceived) dominant trends, differ from **peripheral** scenarios focusing on unexpected developments and genuine ‘surprising’ events. Several choices on the suitable foresight methodology are to be made. The SEPIA choices are elucidated in section 3.1.

### 2.3 Multi-criteria decision support

The multi-dimensional nature of sustainability imposes that public plans or strategic decisions are evaluated with procedures explicitly integrating a broad set of (possibly conflicting) points of view. Hence, multi-criteria evaluation is a most appropriate decision framework (Kowalski et al., 2009). A variety of multi-criteria decision support tools can be used in sustainability assessments under both the ‘policy as discourse’ and the ‘policy as calculus’ philosophy. Each analysis method is based on specific assumptions and supports only a certain type of analysis. The preference for one particular tool must follow from its fitness for the problem characteristics and the desired scope/features of analysis. A promising start for reflection on the application of multi-criteria decision support in sustainability assessment is provided by Munda (2004) and Granat and Makowski (2006). For complex decision-making problems Munda (2004) developed the ‘social multi-criteria evaluation’ technique, applied to wind farm location problems by Gamboa & Munda(2007). Granat and Makowski (2006) find as required properties of a multi-criteria decision analysis tool for a stakeholder evaluation of energy technologies and scenarios at the European level:

- the multi-criteria method can handle criterion scores of a different nature (‘crisp’ scores, stochastic scores, ‘fuzzy’ scores, etc.);
- in general, simplicity is a very desirable characteristic of the multi-criteria decision process – i.e. the number of *ad hoc* parameters used should be limited (preferably only information on weights and on scores should be used as exogenous inputs);

- criterion weights should be seen as ‘importance coefficients’ (and not as numerical values allowing for full compensability between criteria or as indicators of a ‘trade-off’ between different criteria);
- information on all possible rankings for each actor should be given (and not only on the ‘optimal’ one, since taking into account second-best or third-best options can reveal a space for compromise solutions compared with other actors’ rankings);
- the multi-criteria appraisal should include a ‘conflict analysis’ (i.e. an analysis of the ‘distance’ between the different actor perspectives, revealing possible groupings into major ‘world-views’). As win-win situations are not always achievable, some trade-offs will have to be made. These trade-offs will then appear in the discussions on values stimulated by the use of the multi-criteria appraisal and will give normative input to consequences of selecting one alternative over another. Mathematical models can then be of assistance in the selection of the most consensual alternative, regroup alternatives according to the results of the conflict analysis, etc.

Section 3.2 gives more details on the SEPIA approach.

### **3. Towards an integrated sustainability assessment for devising sustainable energy strategies: the Belgian case**

#### **3.1 Foresight methodology**

Corresponding to SEPIA’s ‘opening up’ logic, the foresight methodology explicitly acknowledges the possibility of different ‘framings’ of the energy system (the ‘socio-technical object’ under consideration) and of the factors that cause long-term changes in this system. Narrative scenario-building is particularly well-suited for ‘opening up’ the system description to, and for exploration of, fundamental complexities and uncertainties (Bunn & Salo, 1993). The construction of scenarios for exploring alternative future developments under a set of assumed ‘driving forces’ has a long tradition in strategic decision making, especially in the context of energy policy (Kowalski et al., 2009). Exploratory scenario-building is criticised for its propensity to limit the space of the possible to only a few probable ‘storylines’ (Granger Morgan & Keith, 2008). The backcasting approach is more suited for long-term and complex problems – such as sustainable development – requiring solutions which shift society away from business-as-usual trends. Backcasting is however often criticised for defining utopian futures with little value for decision makers in the ‘real world’.

For combining the strengths of explorative and (traditional) backcasting methodologies SEPIA developed a ‘hybrid backcasting’ approach. ‘Traditional’ backcasting starts from future visions – i.e. a quantitative and qualitative interpretation of a ‘sustainable energy system’ in 2050. From this, we worked backwards to define the pathway that links the ‘here and now’ (i.e. the energy system in 2009-2010) to the ‘there and then’ (i.e. the energy system in 2050). Pathways were built with rather traditional scenario-building methods. A ‘scenario’ resulted from the combination of a vision and a pathway.

Scenario building (following a hybrid backcasting approach) takes place starting from a systematic exploration of futures, by studying many combinations resulting from the breakdown of the energy system. The process of ‘breaking down’ the system implies the definition of a set of factors, which could each influence the development of the energy system into different directions. These possible developments are formulated as ‘hypotheses’ or ‘possible configurations’. The total number of combinations represents a

‘morphological space’, which must then be reduced to a number of coherent sets by formulating transition conditions (‘exclusions’ and ‘compromises’) congruent with reaching the sustainability visions. For this process, we proceeded in a number of separate steps (cf. Fig. 1). These steps are explained in sections 3.1.1 - 3.1.6. The scenario-building phase relied on qualitative in-depth deliberative workshops with the scenario builders group (SBG), and the SEPIA team acting as ‘scientific secretariat’, delivering input materials for the workshops (e.g. information sheets) and processing the outcomes. Scenarios were reviewed by the stakeholder panel (SHP).

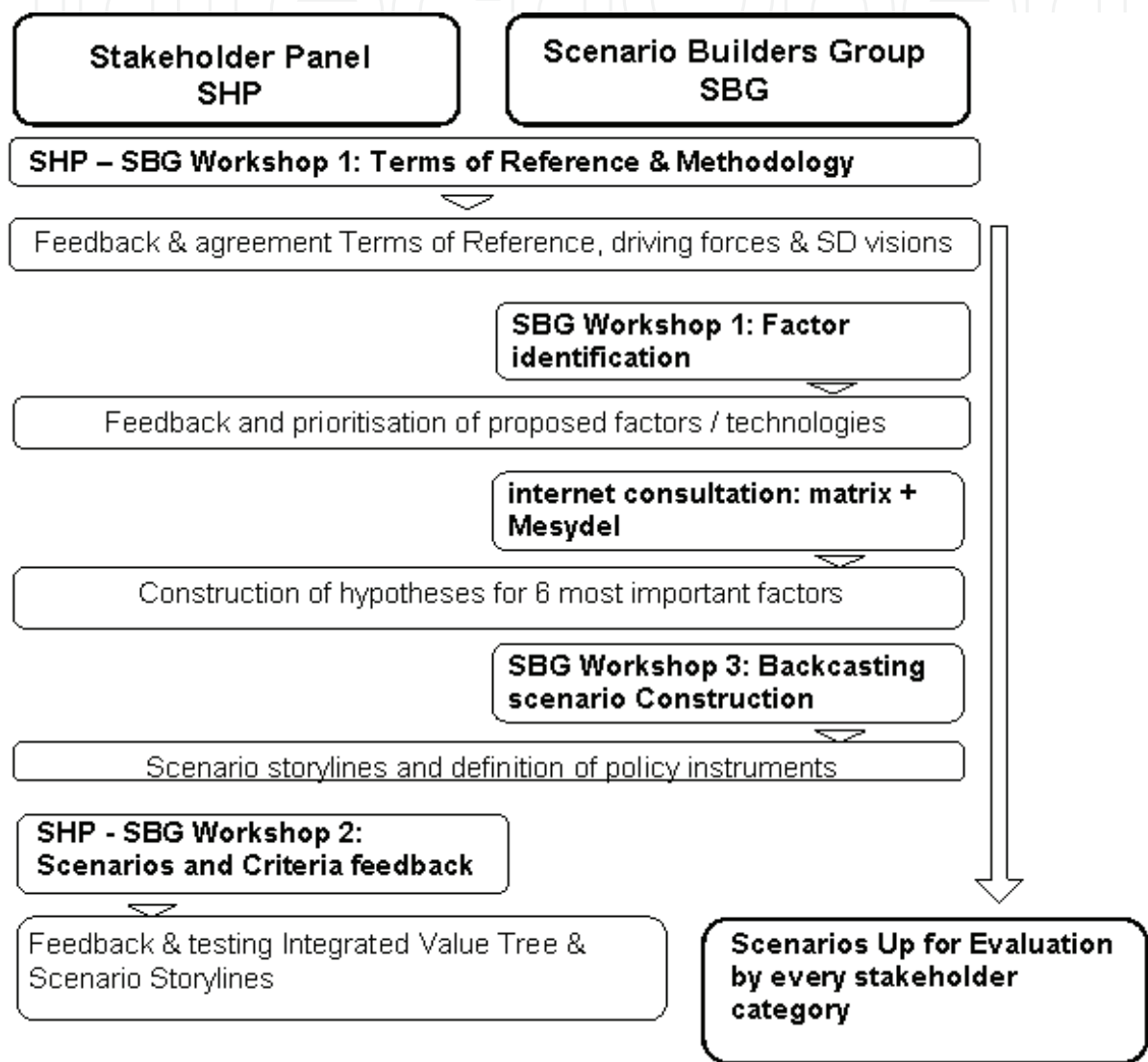


Fig. 1. Scenario-building steps in the context of the SEPIA project

Social mapping was used for composing the SBG and SHP groups respecting the following criteria:

- **Scenario Builders Group (SBG):** The SBG is responsible for developing the long-term energy scenarios describing the different possible visions on a sustainable energy future (horizon 2050) and the pathways (including policy instruments) needed to realise those visions. We expected from each participant to contribute their expertise and personal experience to the discussions. The Scenario Builders were asked to participate on



personal title and not as a representative of the organisation in which they are active. The participants were generally willing to engage in an open, creative, non-judgemental foresight process. Members of the SBG are contacted by the SEPIA team and submitted for approval to the steering committee.

- **Stakeholder Panel (SHP):** The SHP is mainly responsible for evaluating the long-term energy scenarios developed by the SBG; though they will also be given an important role in setting the general directions for these scenarios and providing feedback on scenario assumptions before the LEAP-modelling will take place. This group aims to be representative of the 'stakes' in the Belgian energy sector. Therefore, it was important to ensure that all the potential social groups with a current or potential interest in the problem had the possibility of being included in the process. When deciding on the composition of groups taking part in participative processes, inclusiveness refers to ideas of *representativeness*, although *not in a statistical sense*. Rather, participants should be selected to represent constituencies that are known to have *diverse and, especially, opposing interests*. No stakeholder group should be composed of a preponderance of representatives who are known to have a similar position or who have already formed an alliance for common purpose. In the case of experts – who are presumed not to have constituencies but ideas – they should be chosen to represent whatever *differing theories or paradigms* may exist with regard to a particular task.

### 3.1.1 SHP-SBG workshop\_1: Terms of reference & methodology

It is clear that before starting to formulate sustainable energy strategies, policy makers and/or relevant stakeholder groups will already have some general ideas about the possible alternative solutions. Before entering the multi-criteria assessment phase (in which a decision about the significance of the possible impacts of the alternatives in terms of furthering the sustainable development agenda has to be made), these general ideas will already have to be worked out to a greater level of detail. It is only as a result of the detailed 'scoping' of the sustainability assessment that the decision alternatives will take on their definitive shape – that is, the 'scoping' provides the necessary consensual ground rules for deciding what counts as a 'reasonable' alternative, the range of alternatives to be taken into account, the level of detail needed to explore each alternative, etc. Scoping is therefore an essential part of the sustainability assessment, and should form the basis of a negotiated 'contract' between the project team, stakeholders, experts and steering committee involved in the project. This 'contract' is called the 'Terms of Reference' (TOR). The SEPIA Terms of Reference were thoroughly discussed in a full-day workshop<sup>3</sup>. Since the (hybrid) backcasting approach adopted in the project essentially relies on normative inputs for the development of desirable end points, the first workshop was for a large part devoted to finding a consensus on sustainability principles.

An **integrated value tree** was developed which discusses the sustainability goals specific to the development of energy systems in more detail. A value tree identifies and organises the values of an individual or group with respect to possible decision options. It structures values, criteria, and corresponding attributes in a hierarchy, with general values and concerns at the top, and specific attributes at the bottom. For the purposes of the SEPIA

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<sup>3</sup> The final version of the SEPIA TOR can be downloaded from the project website (<[www.ua.ac.be/sepia](http://www.ua.ac.be/sepia)>).



project, the integrated value tree integrates *fundamental sustainable development (SD) objectives, scenario pathway SD principles, SD (sub-)dimensions and SD indicators*.

**Fundamental SD objectives** are objectives which have to be aimed for ultimately in each long-term energy scenario (though not necessarily by 2050). They are considered to be fundamental to the notion of sustainability and of equal standing. However, because of different interpretations of these objectives, different views on priorities, and the inherent uncertainty of long-term societal evolutions, choices will have to be made. These choices are made apparent in the different visions. In order to establish a consensual list in line with the broad political debate, the fundamental SD objectives referred to widely shared objectives (embedded in international treaties and constitutions, e.g. article 2 of the UNFCCC or the Millennium Development Goals). In other words, they are derived as much as possible from international commitments subscribed to by the Belgian state.

For the purposes of the SEPIA project, we used the following list of fundamental sustainability objectives related to energy system development. These were inspired by the objectives defined by the Belgian federal council on sustainable development (FRDO/CFDD), by the federal planning bureaus' 'Sustainable Development Goals'<sup>4</sup> and international commitments (cf. Table 3).

**Scenario pathway SD principles** are five Rio principles most often used by Belgian governments which have to be respected on the pathway towards the SD visions:

- Global responsibility;
- Integration of all dimensions of development (social, institutional, environmental, economic);
- Inter- and intragenerational equity;
- Precaution;
- Participation of civil society in decision making.

However, these principles are formulated in a rather general way and are subject to divergent interpretations in the different long-term energy pathways.

**SD (sub-)dimensions** are the constituent dimensions of sustainability covering all possible areas of interest related to sustainability assessment of long-term energy scenarios (for some of which fundamental SD objectives are defined). The top-level dimensions relate to the economic, ecological, social and institutional dimensions of SD.

**SD indicators** are the measurable variables resulting from a decomposition of SD into its (sub-) dimensions. SD indicators will be used to score the different long-term energy scenarios.

As mentioned before, the SEPIA integrated value tree incorporates all the previously mentioned sustainability dimensions. In practice, the value tree supported both the construction of long-term energy scenarios by the 'scenario builders group' and the evaluation of these scenarios by the 'stakeholder panel'. Different interpretations/prioritisations of fundamental SD objectives and scenario pathway SD principles lied at the basis of different visions on the long-term future of the Belgian energy system and the pathways needed to get there. Using a backcasting approach, the consequences of different long-term sustainability visions (horizon 2050) were explored using foresight methods for the near (e.g. 2012), mid- (e.g. 2020/2030) and long-term (2050) future. The more detailed development of these

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<sup>4</sup> Taken from Belgium's fourth federal report on sustainable development.

fundamental objectives into a hierarchy of (sub-)dimensions (attributes) and associated indicators will guide the stakeholder evaluation process (cf. Section 3.2).

8 ultimate objectives of the FRDO/CFDD	SDG's 4 <sup>th</sup> SDR	International commitments
1. To provide an effective answer to the challenge of climate change consistent with Article 2 of the UN Framework Convention on Climate Change <sup>5</sup> . During the first SEPIA workshop (17 Nov. 2008), a consensus on an 80% GHG emission reduction target for Belgium by 2050 (reduction by the Belgian economy with the exclusion of offsets) was reached.	SDG 13	UNFCCC Art 2
2. To provide access for all to basic energy services and by doing so contribute to the improvement of living conditions and the creation of wealth and jobs.	SDG 1, 2, 3	JOPI 9,9a,g 10.b; Rio 92 Principle 5, MDG 1
3. Pursuing the use of (almost) non-depletable natural resources.	SDG 13,15,16	JOPI 9a, 15. 20c
4. Pursuing demand side management	SDG 11,14	JOPI 9a
5. Characterised by an optimal energy-efficiency	SDG 11,14	JOPI 9a, 15
6. Causing a minimal health impact on mankind and ecosystems	SDG 7,11, 12	JOPI 7.f, 15
7. Owning a high standard of reliability		JOPI 9.e,f, 20e
8. Implying an affordable cost		UNFCCC Art 3.3 JOPI 20b,e

JOPI = Johannesburg Plan of Implementation  
Rio 92 = Rio Declaration on Environment and Development  
SDG = Sustainable Development Goal (defined by Federal Planning Bureau)  
SDR = Sustainable Development Report (written by Federal Planning Bureau)  
UNFCCC = United Nations Framework Convention on Climate Change

Table 3. Fundamental sustainability objectives used in the context of the SEPIA project

3.1.2 SBG workshop\_1: Factor identification

For the first SBG workshop, the SEPIA project team developed brief explanations and ‘fact sheets’ for about 50 major factors (trends, tendencies) / technological developments expected to have an impact on long-term Belgian energy system development. A ‘factor’ was defined as anything that could influence energy system development in the long run. This workshop was meant to explore the possible factors of change without pronouncing an

<sup>5</sup> The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.

opinion on the desirability of certain evolutions. Only in the later process steps possible factor evolutions were connected with desirable visions on the long-term energy future. During the workshop comments, suggestions and remarks on current state, predictability, possible states (hypotheses) and time horizon of change (slow evolution vs. sudden change) of different factors were elicited.

T8 Advances in energy storage technologies
P2 EU internal energy market policy
T1 Competitiveness of energy conservation technologies for stationary end uses
Ex3 Structural changes to the Belgian economy in a globalised environment
Ex13 Location
P1 EU energy vulnerability strategy
P3 EU energy RD&D strategy
P4 Price instruments to internalise externalities
T13 The ‘hydrogen economy’
T6 Advances in renewable energy technologies
T14 The ‘electric economy’
Ex 11 Ecological and health constraints
T10 ICT technology innovations
B5 Active public involvement in environmental issues
Ex 12 Market environment
Ex 9 Energy price dynamics
P9 Land use policies
B6 Risk perception and evaluation
B8 Shifts in demands for housing and living space/comfort
P8 Stranded assets & Lock in
P7 Importance of social policy
T2 Energy efficiency of various transport modes: technological progress

Table 4. List of 22 factors selected during SBG-W1

The afternoon session of the workshop continued with the identification and selection of about 20 most important factors rated according to their impact on reaching sustainable development objectives in 2050. The results of the individual point allocation (green and red dot stickers) as well as the bailout points (blue dot stickers) resulted in the definition of the guiding factors for the SEPIA exercise. The participants agreed on selecting 22 factors instead of 20 as to avoid wasting valuable time in discussions. The final list of 22 factors was accepted after the question “*Do we all agree on this?*” (cf. Table 4).

3.1.3 Internet consultation: Matrix exercise

The list of 22 factors with a likely influence on energy system development was consequently submitted to the SBG in an internet consultation in order to perform a cross-impact analysis of interdependencies between factors. The cross-impact analysis was performed by asking the members of the SBG to fill in a 22 x 22 matrix with the 22 factors

represented in the rows and columns of the matrix. Each cell of the matrix represented the impact of the factor in the row on the evolution of the factor in the column (score between 0 and 3; 0 = no impact; 3 = high influence). By adding together the scores of all members of the SBG, factors could be classified into the following groups:

- **Determinants:** factors with a high influence on the development of other factors, without being influenced much in return. In other words, these factors act as 'motors' or 'restraints' for the development of energy systems;
- **Strategic variables:** factors with both a high influence and dependence on other factors. These factors are likely candidates for the development of broad strategic actions plans, provided they can be 'steered' by political interventions;
- **Regulatory variables:** factors with both a mid- to low influence and dependence on other factors. These factors can be taken into consideration when designing specific policy instruments, provided they can be 'steered' by political interventions;
- **Dependent variables:** factors which are highly dependent on the evolution of other factors. These factors can be likely candidates for monitoring efforts;
- **Autonomous variables:** factors which evolve largely independently of other factors.

Based on this matrix exercise, 6 factors were selected (3 determinants and 3 strategic variables) that would serve as the 'backbone' for the scenario storylines (developed in SBG-W3):

- Ecological & health constraints;
- Energy price dynamics;
- Market environment;
- Use of price instruments to internalise externalities;
- EU energy RD&D strategy;
- EU energy vulnerability strategy.

### 3.1.4 Internet consultation: Mesydel

At the start of the second phase of the internet consultation, the project team developed 2-3 hypotheses with regard to the long-term evolution for each of the 6 most influential factors. These hypotheses were submitted to deliberative feedback by members of the SBG with the aid of the 'Mesydel' tool<sup>6</sup>. With Mesydel, questions are encoded on a central computer and an access to the software is given to each expert. At any time they could come back to the software and amend or augment their answers. The mediator, for his part, has access to a series of answers classification tools: ability to mark the answer's relevance, to note if he will or will not work later on the question, to comment on the answers (these comments are for his exclusive use) and – the most interesting feature – to give "tags" (keywords) to answers. These tags could then be classified according to topics selected by the mediator. These classification tools allow the mediator a huge flexibility in his work and help optimising his results by allowing him finding very quickly all relevant messages on a given topic. The 'Mesydel' round thus resulted in amended versions of the hypotheses developed for each of the factors.

### 3.1.5 SBG workshop\_3: Backcasting scenario construction

Starting from the processed results of the internet consultation (priority factors, short description of possible alternative hypotheses for their evolution), the members of the SBG

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<sup>6</sup> For more information, see <<http://www.mesydel.com/mesydel.php>>.

developed three scenario 'skeletons' composed of factor hypotheses and technological developments congruent with the logic of reaching the 8 sustainability objectives (cf. Section 3.1.2). This can be done by a formal consistency check; however – in view of the highly resource-intensive mathematical character of this procedure (and the need for supporting software) – we chose a more **intuitive** method. Starting from a certain factor, a hypothesis was selected and then connected to other hypotheses (for the other factors) that were deemed to be consistent with the initial hypothesis. This combination of hypotheses could then be regarded as an alternative 'solution' to the problem of moving towards the attainment of the 8 sustainability objectives in 2050. These combinations were then taken as a basis for the construction of a scenario, and the procedure was repeated until the SBG felt that they had covered the range of possibilities with their scenarios.

For each of the scenario skeletons (which both enable and constrain certain developments), the SBG group had to explore in which other factors (taken from the original list resulting from SBG-W1, cf. Section 3.1.2) – i.e. technologies, behavioural changes, broad policy choices etc. – 'critical' changes had to be achieved (compared to now) in order to achieve a certain vision on a Belgian energy system in 2050 which is supportive of the 8 sustainability objectives. They also had to indicate an approximate timing of the changes needed in the 'critical' factors. Finally, in order to complete the pathways, the SBG group had to **backcast** the necessary policy interventions needed on the Belgian level for reaching the 8 sustainability objectives, given a certain combination of a vision and pathway elements as the policy context. The backcast had to give an answer to the question: *"What is needed at the Belgian (i.e. federal and regional) level in order to realise the changes in the factors within the timeframe indicated by a particular pathway?"*. Although the workshop discussions lead to many interesting suggestions, we did not succeed in constructing pathways in sufficient detail in order to serve as an input to the LEAP energy system model. A detailed backcast also proved to be too demanding a task, mainly due to the rather low attendance. A lot of decisions still had to be made. As a consequence, the project team decided to change the format of the final workshop to some extent, dedicating it also to the further construction of scenarios storylines.

### 3.1.6 SHP-SBG workshop\_2: Feedback on scenario storylines and criteria

The last workshop, which combined inputs from the SHP and SBG, served a dual purpose: deliberation and feedback on a draft value tree as proposed by the project team (with 'fact sheets' unequivocally explaining each indicator, potential data sources and possible measurements (e.g. quantitative/qualitative), taking into account uncertainties); and feedback and further development of the 'scenario skeletons' developed by the SBG in the previous workshops. The value tree was modified according to the feedback received<sup>7</sup>. Deliberative feedback on the scenario skeletons resulted in more needed specifications on the scenarios to serve as an input into the LEAP modelling exercise; however, a lot of 'room for interpretation' was still left for the project team. At the time of writing this chapter, the SEPIA scenarios were still under development. Therefore, for the time being we can only give a qualitative description of the three scenario storylines serving as an input for further modelling.

A first storyline called *"Global consensus"* starts from the assumption that climate change concerns dominate energy system development, in the sense that early and drastic emission

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<sup>7</sup> The final version can be downloaded from the project website (<[www.ua.ac.be/sepia](http://www.ua.ac.be/sepia)>).



cuts are called for (e.g. an EU target of -30% in 2020 compared to 1990). Energy RD&D spending on the EU level is increased substantially and is geared towards realising a common European vision – a low-carbon energy system with maximum penetration of renewable and distributed energy sources. RD&D focuses on technological ‘breakthroughs’ for the achievement of the common energy system vision (e.g. advances in ICT, large offshore wind parks, smart grids, energy storage technologies, nanotechnology etc.). Those solutions mostly require big investments in new supply technology and/or new infrastructures (cf. the ‘Supersmart grid’)<sup>8</sup>. Technologies that are labelled as ‘risky’ encounter strong public and political opposition. A combination of low public acceptance and unresolved waste, safety and proliferation issues leads to a rejection of the nuclear option: without public backing, investments in new nuclear power plants simply become too risky for private investors. Existing plants are shut down as they reach the end of their projected lifetime, and lifetime extensions are not considered. Public support for carbon capture & storage (CCS) is also reluctant. By 2050, energy supply is largely based on renewable energy sources.

In the “*Oil shock(s)*” storyline, the oil (and possibly also the gas) market goes through a series of crises in the period 2010-2030, caused by physical (peak production or refinery capacities are surpassed) or political factors (e.g. crisis in the Middle East), resulting in sudden and unpredictable price increments. Leading powers try to control the remaining resources by engaging in strategic alliances, as energy policy is to a large extent dictated by foreign policy and security considerations. Energy security is the main concern over the short to mid-term, leading to a focus on energy efficiency (on the demand side) and on available technologies that alleviate the dependence on imported oil & gas (on the supply side): renewables (mainly wind energy and biofuels), coal (later equipped with carbon capture and storage) and prolonging the lifetime of existing nuclear power plants. Thanks to these measures, energy security concerns are alleviated over the period 2030-2050, allowing the climate change agenda to take over as a priority issue.

Finally, the “*Confidence in RD&D*” storyline stands for a scenario where a combination of high oil (and gas) prices, climate policy and competitive energy markets decisively influence the pace of transition to a low-carbon energy future in the OECD countries. In the EU the Lisbon agenda (and possible successors) carries high priority. The EU protects and expands its previous economic achievements, including the internal energy markets. However, governments are still heavily involved in securing their external energy supplies (this goes for ‘government’ as well on the EU as on the national level in Europe), albeit in a more subtle and indirect way than in the “*Oil shock(s)*” scenario. In general, market forces determine the investments choices made by energy industry between renewables, ‘clean coal’ or nuclear power, but public and/or political perceptions sometimes lead to targeted interventions. The use of the nuclear option is especially closely associated to national preferences. Independently from the developments in the fields of nuclear, Europe is on its way to a smooth and accelerated transition towards renewable energy. The process is quite similar to the one described in “*global consensus*”, although the share of renewable energy sources is smaller. Large off-shore wind farms are the most important renewable source for electricity production and biomass playing a major role in heating or cogeneration. In addition, because of the higher demand, highly efficient gas- and coal-fired power plants with CCS are needed in this scenario. Decentralised power generation is a growing trend in

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<sup>8</sup> More information on the ‘Supersmart grid’ concept can be downloaded from <[www.supersmartgrid.net](http://www.supersmartgrid.net)>.

the coming 50 years. The increase in energy efficiency is also determined by market forces as new energy end-use technologies emerge in electricity use, space heating, 'smart' decentralised energy systems and transportation.

3.3 Fuzzy-set multi-criteria decision support

As mentioned in the introduction to this chapter, the scenarios developed for the SEPIA project have not been evaluated yet with the aid of the multi-criteria decision support tool. To claim the motivation of the use of fuzzy-set multi-criteria analysis, we briefly introduce the reader to the principles of fuzzy logic and the particular advantages of using a fuzzy-logic multi-criteria group decision support tool named DECIDER, which was chosen for the evaluation of the energy scenarios by the stakeholder panel in the context of the SEPIA project based on earlier experiences (Ruan et al., 2010).

3.3.1 Fuzzy logic

Fuzzy logic deals with reasoning that is approximate rather than precise. In fuzzy logic the truth degree of a statement can range between 0 and 1 and is not constrained to the two truth values {true, false} or {yes, no} as in classic binary logic. And when *linguistic variables* (Zadeh, 1975) are used (as is the case in the DECIDER tool), these degrees are modelled by specific mathematical functions (e.g. membership functions in fuzzy logic as shown in Fig. 2). The difference between 'classic' and 'fuzzy' logic can be illustrated by the example of a 100-ml glass containing 30 ml of water. We may consider two concepts: 'Empty' and 'Full'. In classic logic, the phrase "the glass is empty" can only have one 'truth value' (i.e. true or false). In fuzzy logic, the meaning of 'empty' or 'full' can be represented by a certain fuzzy set. One might define the glass as being 0.7 empty and 0.3 full. Clearly, the concept of 'emptiness' is subjective and would depend on the observer or designer. Another observer might equally well consider the glass to be 'full' for all values down to 50 ml. It is essential to realise that fuzzy logic uses truth degrees as a mathematical model of the vagueness of human judgement which is quite simply prevalent in all kinds of decision situations. To illustrate the use of *linguistic variables*, consider the example of the temperature of the liquid contained in the glass. Each function maps the same temperature value to a truth value in the 0 to 1 range. These truth values can then be used to determine e.g. whether the liquid is too hot or too cold to drink.

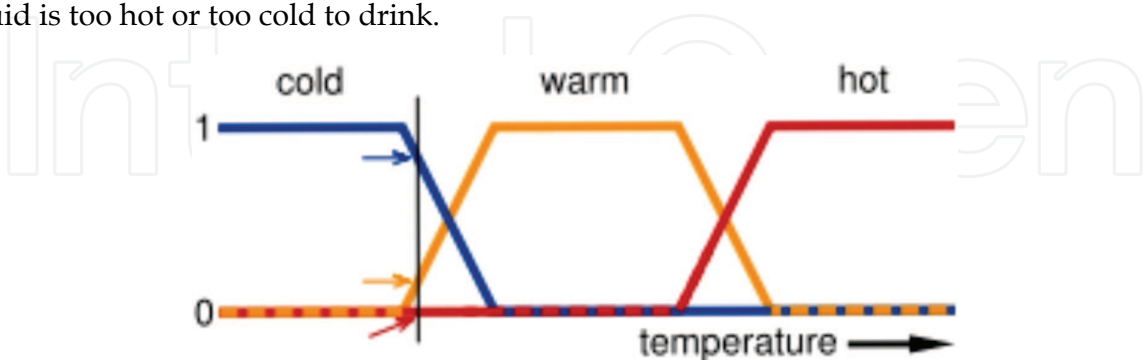


Fig. 2. Illustration of membership functions

In this image, the meaning of the expressions cold, warm, and hot is represented by functions mapping a temperature scale. A point on that scale has three 'truth values' - one for each of the three functions. The vertical line in the image represents a particular temperature that the three arrows (truth values) gauge. Since the red arrow points to zero,

this temperature may be interpreted as “not hot”. The orange arrow (pointing at 0.2) may describe it as “slightly warm” and the blue arrow (pointing at 0.8) “fairly cold”.

### 3.3.2 Application of fuzzy logic to sustainability assessment

It is fair to say that some clear measures or, at least, indicators of sustainability exist, but the overall effectiveness of policies towards a goal of sustainability cannot be assessed. Attempts have been made to measure sustainability using the economical, the ecological, or a combined ecological-economic approach, but the results still lack universal acceptance (Laes, 2006). For the sake of analysis, researchers have broken down sustainability into a large number of individual components or indices whose synthesis into one measure appears to be next to impossible. As pointed out in the literature, it is not so much that environmental and socio-economical information is lacking but the fragmentary, often qualitative, and very detailed nature of this information hampers its direct usefulness in policy making. Not only are there no common units of measurement for the indicators of sustainability, but quantitative criteria for certain values are lacking. A systemic method based on a reliable scientific methodology, which combines multidimensional components and assesses uncertainty, is needed. In reality, the border between sustainability and unsustainability is most of the time not sharp but rather fuzzy. This means that it is not possible to determine exact reference values for sustainability, and a scientific evaluation of uncertainty must always be considered in the procedure of sustainability assessment. For this reason, the use of natural language and linguistic values based on the fuzzy logic methodology (Munda et al., 1994) seems more suitable to assess sustainability.

Multi-criteria analysis with linguistic variables, commonly known as fuzzy-set multi-criteria decision support, has been one of the fastest growing areas in decision making and operations research during the last three decades. The motivation for such a development is the large number of criteria that decision makers are expected to incorporate in their actions and the difficulty of expressing decision makers' opinions by crisp values in practice. Group decision making takes into account how people work together in reaching a decision. Uncertain factors often appear in a group decision process, namely with regard to decision makers' roles (weights), preferences (scores) for alternatives (scenarios), and judgments (weights) for criteria (indicators) (Lu et al., 2006). Moreover, multi-criteria analysis aims at supporting decision makers who are faced with making numerous and conflicting evaluations. It highlights these conflicts and derives a way to come to a compromise or to illustrate irreducible value conflicts in a transparent process. Firstly, as decision aiding tools, such methods do not replace decision makers with a pure mathematical model, but support them to construct their solution by describing and evaluating their options. Secondly, instead of using a unique criterion capturing all aspects of the problem, in the multi-criteria decision aid methods one seeks to build multiple criteria, representing several points of view. In particular, fuzzy-set multi-criteria decision support respects the principles of the 'policy as discourse' approach as set out in Section 2.3. Lack of space in the context of this chapter hinders us to give a full demonstration; we will illustrate however how DECIDER is able to deal with different types of information.

### 3.3.3 Handling different types of information with the DECIDER tool

Quantitative and qualitative information (or data) used in the evaluation of scenarios will be of very different nature; it may be heuristic or incomplete or data that is either of unknown

origin or may be out of date or imprecise, or not fully reliable, or conflicting, and even irrelevant. In order to allow an adequate interpretation of the information from the stakeholder evaluation, the DECIDER tool was further modified in order to deal with various uncertainties that result in various data formats in practice. For application in the context of sustainability assessment it was considered advantageous to have a sound and reliable mathematical framework available that provides a basis for synthesis across multidimensional information of varying quality, especially to deal with information that is not quantifiable due to its nature, and that is too complex and ill-defined, for which the traditional quantitative approach (e.g., the statistical approach) does not give an adequate answer.

Within the SEPIA project, we the following data formats can be handled by DECIDER:

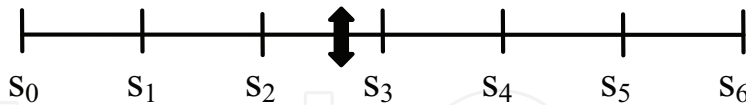
1. *Information (data) presentation with different formats*

**Type A.** Numerical Value – It is the most common way of indicating information scale. Any information  $\alpha$  takes values in a  $[0, C]$  interval, where 0 is the lowest and predetermined C value is the highest level of possible judgments.  $C = 1$  and  $C = 100$  cases are the most frequently used ones.

**Type B.** Interval Value – any interval of  $[0, C]$  may give sufficient information.

**Type C.** Linguistic Value – It is sometimes more appropriate to indicate information with linguistic terms (fuzzy sets) instead of numerical values. In this type,  $\alpha$  takes values from a predetermined linguistic terms set. Let  $S = \{S_i\}$ ,  $i = \{0, \dots, m\}$  be a finite and totally ordered term set. Any label,  $s_i$ , represents a possible value for a linguistic variable. The semantics of the finite term set  $S$  is given by fuzzy numbers defined in the  $[0, 1]$  interval, which are described by their membership functions. For instance,  $S = \{S_i\}$ ,  $i = \{0, \dots, 6\}$ , in which the following meanings to the terms are assigned -  $S_0$ : none,  $S_1$ : very low,  $S_2$ : low,  $S_3$ : medium,  $S_4$ : high,  $S_5$ : very high,  $S_6$ : excellent.

**Type D.** 2-tuple (Continuous linguistic value) – When it's hard to make information with discrete linguistic terms, then one can indicate some information between  $S_2$  and  $S_3$  below.



**Type E.** Distribution over linguistic values

A belief structure could be used as for instance to represent general belief of the information with a given situation. Such that, to evaluate a performance of scenarios vs. criteria, for example, an expert may state that he is 20% sure it (the relationship between scenario  $x$  and criterion  $y$ ) is  $S_1$ , 50% sure it is  $S_2$ , and 30% sure it is  $S_3$ . In this statement  $S_1$ ,  $S_2$ , and  $S_3$  are linguistic evaluation grades and percentage values of 20%, 50%, and 30% are referred to as the belief degrees, which indicate the extents that the corresponding grades are assessed to.

2. *Information aggregation with various certain and uncertain theories*

After having obtained all formats of information, one can transfer all information from the types A, B, C, and D to the type E. Thus all well-known theories such as set theory, probability theory, possibility theory, fuzzy set theory, and evidence theory can be selected and applied depending on the nature of uncertainty of the information.



Different aggregation techniques can be also applied for different needs of the decision analysis support.

### 3. *Final decision support scenarios*

By using the type E-based approach in (I), one can deal with efficient uncertain information, especially, when missing information appears during the decision analysis within the project. Typically, missing information could be (a) stakeholders don't know/understand the information; (b) stakeholders don't have any information; (c) stakeholders think the information is irrelevant. Most traditional approaches would have some difficulty to deal with such missing information.

## 4. Concluding observations

Sustainability assessment of energy policy strategies is performed at the interface between scientific theory-building and political practice. Therefore, practical sustainability assessments are judged by criteria like scientific soundness, political legitimacy and practicability (in a real political setting). In this chapter, we offered a reflection on how such criteria can be met, based on experiences from the SEPIA project. Indeed, presumes that deciding on an appropriate (i.e. sustainable) long-term energy strategy is at least a suitable 'test case' for a more deliberative (discursive) governance arrangement, *ergo* that it is not *a priori* better handled by alternatives such as (a combination) of free market competition, lobbying and/or direct government regulation (top-down 'government' as opposed to bottom-up 'governance'). Further in-built presuppositions include that some particular composition of actors is thought to be capable of making decisions according to (voluntarily accepted and consensually deliberated) rules, that will resolve conflicts to a maximum extent possible and (ideally) provide the resources necessary for dealing with the issue at hand. Moreover – next presupposition – that the decisions once implemented will be accepted as legitimate by those who did not participate and who have suffered or enjoyed their consequences. Also different from standard science practice, foresight knowledge is non-verifiable, since it does not give a representation of an empirical reality. All together, substantiating the quality of the SEPIA approach is challenging, in theory and in practice, as documented by the following observations.

The SEPIA methodology aligns with theory-building in ecological economics, decision analysis, and science and technology studies, favouring the combination of analytical and participatory research methods in the field of 'science for sustainability'. This view is motivated by sustainability problems being multi-dimensional (thus limiting the use of only monetary cost-benefit analysis), of a long-term nature (thus involving significant uncertainties) and applying to complex socio-economic and biophysical systems (thus limiting the use of mono-disciplinary approaches). SEPIA shows the advantages of combining a (hybrid backcasting) scenario approach with a (fuzzy logic) multi-criteria decision aiding tool. Scenario exploration allows taking into account the (socio-economic and biophysical) complexities of energy system development so that uncertainties on the long term can be explored. Multi-criteria methods, and especially those based on fuzzy-set theory, are very useful in their ability to address problems that are characterised by conflicting assessments and have to deal with imprecise information, uncertainty and incommensurable values. Both methods are supported by a large body of scientific literature, ensuring that an effective check of 'scientific soundness' can be made through the peer review process. However, the application of these methods, and especially their



participatory nature, are challenging in practice. For instance, the combination of narrative scenario building and quantitative modelling in theory necessitates the need for a deliberative consensus on all parameters used in the model, which in practice turns out to be impossible to organise (the LEAP model requires hundreds of inputs). The scenario development phase as it was already turned out to be time intensive for stakeholder participants. We struggled with non-participation and dropouts of stakeholders; without proper investigation we for the time being cannot explain why participation fluctuated as it did. However, at least part of the explanation can probably be found in the general impression that the potential players in the Belgian energy system transition landscape – how limited their number may be – are rather scattered. In Belgium (as in many other countries), energy problems cross a varied set of policy domains and agendas, such as guarding the correct functioning of liberalised energy markets, promoting renewables, environmental protection, climate policy etc. These are dealt with by different administrative ‘silos’ and analysed by separate groups of experts and policymakers. As a result of this fragmentation, a lot of the key players struggle with overloaded agendas, organisation specific expectations and performance criteria and hence find no time for explicit reflective/exchange moments in the context of a scientific project not directly connected to any actual decision-making process. There may be many contacts on the occasion of events and by communication means, but there is not a structured exchange of experiences, knowledge and mutual feedback (‘structured’ in the sense of embedded in a culture of working methods). This impression of fragmentation sharply contrasts with the high priority assigned to institutionalised networks and collaboration in the context of ‘transition management’. Perhaps the best way to sum up the findings so far is: assessing scenarios in the form of transition pathways towards a sustainable energy future with the aid of a participatory fuzzy-logic multi-criteria decision aiding tool certainly has the potential to support a more robust and democratic decision-making process, which is able to address socio-technical complexities and acknowledges multiple legitimate perspectives. However, these methods are time- and resource intensive and require the support of adequate institutional settings for a proper functioning in real political settings. Participation in integrated energy policy assessment should therefore not be taken for granted. We hope that the experience gained so far in the context of the SEPIA project will allow future initiators of similar participatory projects to level the project objectives, the participants’ expectations and the political backing with each other, a prerequisite for successful participation in foresight exercises.

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The world's reliance on existing sources of energy and their associated detrimental impacts on the environment- whether related to poor air or water quality or scarcity, impacts on sensitive ecosystems and forests and land use - have been well documented and articulated over the last three decades. What is needed by the world is a set of credible energy solutions that would lead us to a balance between economic growth and a sustainable environment. This book provides an open platform to establish and share knowledge developed by scholars, scientists and engineers from all over the world about various viable paths to a future of sustainable energy. It has collected a number of intellectually stimulating articles that address issues ranging from public policy formulation to technological innovations for enhancing the development of sustainable energy systems. It will appeal to stakeholders seeking guidance to pursue the paths to sustainable energy.

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